NISTIR 5651

Algorithm Testing and Evaluation Program for Coordinate Measuring Systems: Long Range Plan

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1 Introduction

This report is a long-range plan for the NIST Algorithm Testing and Evaluation Program for Coordinate Measuring Systems Special Test Service and is intended to be reviewed and updated periodically. The audience is the NIST Calibration Advisory Group (CAG). The CAG was established by the NIST Director to provide broad oversight for the NIST Calibration Program and related calibration activities. The CAG advises the NIST Director and Operating Unit (OU) Directors on matters relative to the quality and management of the calibration services. CAG also develops and provides guidelines for new calibration services to be offered. One of the guidelines states that new calibration or test service providers develop and update long-range plans. The purpose of the long-range plan is to outline the projected evolution of the service so that the service evolves systematically.

2 ATEP-CMS Background

The NIST Algorithm Testing and Evaluation Program for Coordinate Measuring Systems (ATEP-CMS) evaluates the performance of data analysis software used in coordinate measuring systems (CMS). ATEP-CMS is the first U.S. Calibration Program test of software used in dimensional metrology [7]. Figure 1 shows a high-level diagram of how ATEP-CMS works.

ATEP-CMS allows customers to submit requests to have their data analysis software tested and evaluated by NIST. NIST then provides the customers with NIST-generated data sets. The customers produce fit results from their data analysis software using the NIST-generated data sets. NIST generates fit results from the same data sets using the NIST Algorithm Testing System's (ATS) reference algorithms [14,15]. The two sets are then compared. NIST then provides the customer with a formal evaluation result.

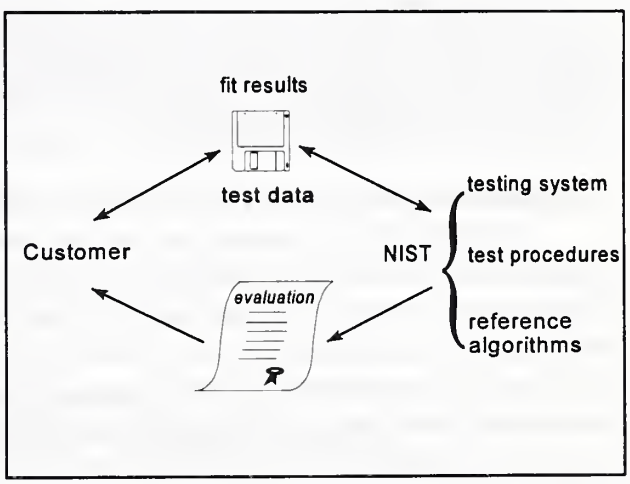

Figure 1 NIST's ATEP-CMS tests and evaluates data analysis software for a given customer by comparing fit results.

ATEP-CMS's objective is to provide the dimensional metrology community with a formal mechanism for testing and evaluating data analysis software in CMSs. ATEP-CMS focuses on three major goals: first, to provide industry with a mechanism for evaluating CMS software;

second, to reduce measurement uncertainties associated with such software; and third, to respond to industry's need for an evaluation service that performs testing of CMS data analysis software.

CMS behaviors, characteristics, and limitations are not fully understood. Since the 1980's efforts have been made to study and evaluate the effects of CMS data analysis software on the total measurement error (measurement uncertainty) of a CMS. Also, European efforts of the German Physikalisch-Technische Bundesanstalt (PTB) [13] and the British National Physical Laboratory (NPL) [6] began to address CMS data analysis software in the early '80s. Concerns in the confidence of results reported by CMSs have been growing since.

- In 1983, PTB held Round Robin Tests.
- In 1983, The American Society of Mechanical Engineers (ASME) started standards work in coordinate measurement machine software and in 1988 held the ASME/NSF Workshop on Mechanical Tolerancing [2].
- In 1988, the Government-Industry Data Exchange Program (GIDEP) [10] issued an alert on CMS software. The GIDEP alert documented problems with tolerance computation software from several different vendors.
- In 1988, ASME and NIST (formerly the National Bureau of Standards (NBS)) held Round Robin testing of reported results from different CMM manufacturers and vendors.
- In 1989, DoD inspectors temporarily shut down production lines due to problems with the inspection software.

Throughout NIST's involvement in addressing the problem of testing and evaluating software found in CMSs, industry has voiced the need for a formal mechanism to test and evaluate CMS data analysis software. From 1993 until now the requests for NIST to provide a testing service for CMS software have increased dramatically.

3 Requirements for ATEP-CMS - Customer Demand

ATEP-CMS is intended to provide service to the dimensional metrology community. Potential customers are CMS vendors for CMMs, vision systems, theodolites, photogrammetry, etc. Other intended customers are for example CMS users in mechanical parts, electronics, geodesy, and anthropometry. Calibration service providers are also possible customers. Currently, NIST has a list of over 80 companies that have expressed interest in ATEP-CMS. Some of these companies have already evaluated the ATS; others have been using the ATS for internal testing; still others have provided feedback for the continuing work. Most of these companies are current potential ATEP-CMS customers.

Providing ATEP-CMS is also economically viable. By some estimates, there exist an estimated 200,000 CMMs in use worldwide with approximately 100,000 installed in the U.S. There are also more than 100 U.S. CMM software producers.

4 Alternatives to NIST providing ATEP-CMS

Dimensional measurements need to be traceable to national standards. ISO 9000, DoD, and many contractual relations require national standard traceability. Currently, there are no formal mechanisms for testing and evaluating CMS data analysis software in the United States. Therefore, there is no traceability available for the output of data analysis software. The lack of this type of traceability breaks the chain of the dimensional metrology standards that are available. There **ARE** standards for dimensional metrology hardware. There **ARE NO** standards for testing and assessing the performance of dimensional metrology software. Yet, the hardware that complies to existing standards runs with software that is not traceable to any standard.

Providing ATEP-CMS at NIST begins to fill the existing gap in the traceability of dimensional measurements. NIST provides the dimensional metrology community with traceability to a national standard of performance through the ATEP-CMS.

Much work has been identified in the area of testing CMS software. The International Organization for Standardization, under its working group ISO/TC 3/WG 10 is working on a standard for software testing. NPL has prepared a document entitled *Proposed DRAFT ISO Standard: Method for Testing Software for Computing Gaussian Substitute Elements in Co-ordinate Metrology* [11]. In addition, Germany offers a service to test CMS software comparing results for test data sets to results obtained from reference software [16]. Also, Great Britain has proposed mechanisms for testing form assessment software [5].

There are no domestic alternatives to the ATEP-CMS service. ATEP-CMS allows U.S. customers to domestically obtain traceability of data analysis results to an internationally recognized calibration body.

5 Resource Requirements

ATEP-CMS makes use of three major components. First is a testing system, in this case the NIST ATS. Second are test procedures based on the ASME B89.4.10 draft national standard [1]. Third are reference algorithms, which are incorporated in the ATS and are used to provide a baseline for performance comparison. The ATS runs on PC class computers. The minimum configuration is as follows:

80286 or higher CPU
DOS Version 3.3 or later
Hard disk with at least 2MB free space
EGA or VGA graphics
High density 5 1/4" floppy drive or 3 1/2" drive
500 KB free memory (recommend minimum of 1MB installed memory)

Optional equipment:
- 80X87 math coprocessor
- Mouse

Resources for providing the ATEP-CMS service include one personal computer configured as above, one person to run the test, one person to verify the test, a calibration manager, and office space with appropriate workstation for personal computers. In addition, secretarial services are required.

6 Planned Evolution of ATEP-CMS

This section addresses the planned evolution of ATEP-CMS in the following three areas: first, the technical scope of ATEP-CMS as a Special Test Service; second, the evolution of ATEP-CMS towards a calibration service; and third, the administration of ATEP-CMS. The projected time frame for this work has not been scheduled at this time. Time schedules will be determined once availability of resources is determined.

6.1 Technical scope of service

NIST laboratories are working with industry (through standards committees) to establish ongoing programs to develop advanced dimensional metrology algorithms. The approach is to establish a research consortium to sponsor and carry out work identified by the national research agenda on dimensional tolerancing and metrology. NIST will participate in the development of new technology and standards for statistical tolerancing and tolerancing of advanced geometries. Collaboration between NIST laboratories will lead to specifying objectives for data analysis algorithms. Work with consortium members will lead to developing new reference software implementations of the algorithms.

Gears, threads, airfoils, and other sculptured surfaces are some of the geometries that will be addressed. Also the evaluation of other fitting criteria like minimum zone, datum fits, and other criteria used in industry will be made available. In addition, NIST will add other CMS software functions to the CMS software evaluation process. Some of these functions are: tolerance zone evaluation, parallelism, position, material condition, and other tolerances from ASME Y14.5 [3,4] and/or ISO 1101 [12]. NIST will track and, where appropriate, incorporate results of ongoing research efforts like NIST's computational metrology competence project and the Consortium For Advanced Manufacturing - International's Dimensional Inspection Techniques Specifications (CAM-I's DITS) effort.

6.2 Evolution towards a calibration service

NIST will track the use of the test service results by industry to evaluate the utility of ATEP-CMS's measured values and measurement uncertainty. Additional research will be done by collecting data on process characteristics and studying the interaction of part deviations, coordinate sampling plans, and data analysis methods. Using these results, performance metrics and assessment methods for new algorithms will be developed. NIST will develop algorithm testing tools based on these metrics and integrate the tools into an algorithm testing environment.

Additionally, through a coordinated research program, NIST will address any shortcomings identified by industry. NIST will also work through appropriate ISO technical committees and working groups to ensure ATEP-CMS methodology is incorporated into international standards for traceability and ISO 9000 certification.

6.3 Administration of the service

In the case where ATEP-CMS requests increase dramatically, NIST will work with research laboratories at the University of North Carolina Charlotte, Cornell, and others, DoD and industry standards laboratories, and other interested parties (determined by advertising) to establish test services under NIST's Measurement Assurance Programs (MAP).

7 Other Information

7.1 Customer Feedback

NIST has maintained communications with the dimensional metrology community via the ASME standards committees. NIST also participates in the ISO efforts in this area. In addition, NIST has made presentations at annual American Society for Quality Control (ASQC) [8] and National Conference of Standards Laboratories (NCSL) [9] conferences. Through these channels, NIST has obtained feedback that is crucial to the continuing efforts of developing methods for testing CMS software.

7.2 Voluntary Standards

NIST's development and implementation of ATEP-CMS complement the work of the standards committees at ASME. In addition, NIST is working with ISO to develop a uniform international approach to dimensional metrology software testing.

7.3 Training

Training is necessary for ATEP-CMS service customers for them to understand and interpret test results. Administrative and technical documentation is available for all ATEP-CMS customers and interested parties. In addition, training is necessary for other personnel that might run the ATEP-CMS service. Currently, there is sufficient documentation to be able to follow the ATEP-CMS administrative process. There are also clear, concise technical reports that would allow an operator to run the ATS, produce test results, and provide an evaluation. However, to be able to have expert ATEP-CMS operators, formal training will be required specifically on using the ATS and using ATEP-CMS to produce evaluations. A formal training plan will be developed in the near future.

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